

PB86-190303

EPA (Environmental Protection Agency)
Research on Indoor Air Quality

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Apr 86



U.S. Department of Commerce
National Technical Information Service

NTIS

PB86-190333

EPA/600/D-86/093
April 1986

EPA RESEARCH ON INDOOR AIR QUALITY

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TECHNICAL REPORT DATA (Please read instructions on the reverse before completing)		
1. REPORT NO. EPA/600/D-86/093	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE EPA Research on Indoor Air Quality		5. REPORT DATE April 1986
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) W. Gene Tucker		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NA		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. NA (Inhouse)
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Published Paper; March 1986
		14. SPONSORING AGENCY CODE EPA/600/13
15. SUPPLEMENTARY NOTES AEERL project officer is W. Gene Tucker, Mail Drop 54, 919/541-2746. At APCA national meeting, Minneapolis, June 1986.		
16. ABSTRACT The paper discusses EPA's research program on indoor air quality. Now in its third year, it is a broad-based program that includes: field surveys of pollutant concentrations in homes, characterization of emissions from sources, health studies of genotoxic and irritant/neurobehavioral effects, and a limited amount of research and development of indoor air quality controls. The primary emphasis in all areas is on organic compounds, except for controls, where emphasis is on particles (although even there the orientation is partly organic, since indoor air respirable particles are mostly organic condensation aerosols). The area of greatest overall emphasis has been on a national field survey of air quality in homes. This field survey will obtain distributions of exposure estimates to indoor and outdoor air pollutants. It will help confirm whether indoor concentrations are in fact much higher than outdoor concentrations, as suggested by several small field studies that have been done to date. Research on indoor sources, health effects, and indoor air quality controls will continue to be significant components of the program. In addition, EPA's basic programs in air pollution research are likely to be increasingly influenced by indoor air quality concerns.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Environmental Biology	Air Pollution Control
Houses	Organic Compounds	Stationary Sources
Surveys	Particles	Indoor Air Quality
Concentration (Composition)		Characterization
Properties	Emission	Health Effects
Analyzing	Toxicity	Particulates
		13B 06F
		13M 07C
		14B
		07D
		14G
		06T
18. DISTRIBUTION STATEMENT Release to Public		19. SECURITY CLASS (This Report) Unclassified
		20. SECURITY CLASS (This page) Unclassified
		21. NO. OF PAGES 14
		22. PRICE

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INTRODUCTION

The U.S. Environmental Protection Agency initiated a research program on indoor air quality (IAQ) in 1984. Extramural funding for this program, through supplemental appropriations from Congress, has been \$2 million per year for each of the three fiscal years since startup. In fiscal years 1984 and 1985, research on radon measurement and mitigation was included in the basic IAQ research program. In the current (1986) fiscal year, a separate \$1.5 million was appropriated by Congress for radon mitigation, which has in effect become a separate program because of the uniqueness of radon as an indoor air pollution problem. The radon mitigation program will be referred to here only briefly, since it has been described in detail elsewhere¹.

OVERVIEW OF THE RESEARCH PROGRAM

The EPA program is a broad-based one in that it addresses, at least to some extent, the full range of fundamental questions about indoor air quality, namely:

- o What are the indoor pollutants of concern?
- o From what sources are they coming?
- o What are the levels of exposures to them?
- o What are their health risks, versus the risks from outdoor exposures?
- o What are the most cost-effective ways to reduce their concentrations?

From the beginning, the program has included projects to develop methods for and conduct field surveys of indoor air quality; to characterize pollutant sources and their emissions; to study health effects of pollutants found in source studies and field surveys; to develop and evaluate various methods of controlling source emissions or cleaning indoor air; and to transfer information among EPA and other IAQ researchers, and to non-research users in the public and private sectors. Early guidance was obtained from a review of EPA's program plans by the research community, at Harvard in December 1983. Several smaller reviews of the components of the program have been held periodically since then. The program has largely been conducted by EPA's air monitoring, health effects, and engineering research laboratories in Research Triangle Park, NC, with radon quality-assurance-related projects conducted by the Agency's monitoring laboratory in Las Vegas, NV.

While the program does touch on most areas of indoor air quality concern, it is by no means comprehensive in any area. At least half a dozen other federal agencies, and several private-sector organizations, are conducting programs that round out indoor air research in the United States. The area of primary EPA emphasis has been on surveying the concentrations of pollutants in U.S. residences. Office building and public access building environments, including the so-called "sick building" situations, have not been directly addressed by the EPA program; this has been the focus of much of the indoor air work by the National Institute of Occupational Safety and Health (NIOSH). EPA's emphasis is partly due to existing field study data that have shown high concentrations of indoor pollutants in homes, and partly due to the great amount of time people spend in homes, especially by those who may be most susceptible; e.g., the young, old, and infirm.

Table I summarizes the areas of needed IAQ research, and indicates those with which EPA's program is involved. A brief comment indicates the type of EPA involvement or other organizations that have such research underway. Through the many interactions among the 16 Federal agencies associated with the Committee on Indoor Air Quality (CIAQ), total coverage of IAQ issues is broad (if not yet deep). Private sector organizations, particularly the Gas Research Institute (GRI), the Electric Power Research Institute (EPRI), and many utility companies, are also doing considerable research on IAQ. In fact, their total funding is probably somewhat higher than the total Federal Government funding. Therefore, private sector programs have also been taken into consideration in planning the EPA program. The following descriptions will expand on the areas listed in Table I. Further details are available in EPA's fiscal year 1985 status report².

MEASUREMENTS OF INDOOR AIR QUALITY

A major part of the EPA program to date has been the design of national field surveys of air pollutants in U.S. homes. This emphasis has resulted from guidance received at the December 1983 peer review meeting, from language in EPA's appropriation bills for indoor air research, and from literature reviews such as the 1981 National Academy of Sciences report that included a recommendation for "A staged assessment of the exposures of the general population to indoor pollutants and of the effects of such exposures on health and welfare ..."³ The overall objective of field surveys is to obtain data on the distribution of indoor concentrations of the measured pollutants in the types of buildings surveyed; in our case, the buildings are homes in the United States. These data are to be used in relative risk evaluations and identifications of possible sources contributing to indoor air pollution.

The first to be designed was a national survey of radon in homes. Because of the strong geological dependence of radon (its primary sources are soil gas and well water), a 50-state survey was prepared. The survey design also took into consideration the importance of building substructures (which affect soil gas entry) in the sampling strategy. Much more is known about radon measurement techniques, sources, and health effects than for most other indoor air pollutants, and radon in homes has recently emerged as a major public health issue. EPA therefore shifted responsibility for radon projects (except research and development of radon mitigation technologies) from the Office of Research and Development to the Office of Radiation Programs, which

Table 1. Areas of needed research in indoor air quality, and EPA research involvement.

<u>Area</u>	<u>EPA IAQ Research</u>	<u>Comments</u>
<u>Measurement of indoor air quality</u>		
o methods development	yes	NO ₂ , particles, VOCs
o pollutant concentrations in buildings	yes	field surveys of NO ₂ , particles, VOCs in residences
o acceptability to occupants	no	"sick building" investigations by NIOSH, DOE, others
<u>Characterization of sources</u>		
o combustion	yes	organic emissions from kerosene heaters
o materials	yes	organic emissions from building materials and consumer products
o activities	no	studies of methylene chloride emissions during use of consumer products by CPSC and EPA/OTS
o outside environment	no	radon from soil gas and well water supplies by DOE, others
<u>Estimation of exposures</u>		
o from IAQ measurements	yes	from EPA, other field surveys
o from source models	yes	organics from combustion and material sources
o from personal monitoring	(yes)	covered by EPA's total exposure program
<u>Estimation and measurement of health risks</u>		
o health endpoints:		
- respiratory effects	yes	NO ₂ , formaldehyde
- sensory irritation	yes	VOCs
- neurobehavioral effects	yes	VOCs
- cancer, other genotoxic effects	yes	tobacco smoke, kerosene heater emissions

(continued)

Table I (continued)

<u>Area</u>	<u>EPA IAQ Research</u>	<u>Comments</u>
o pollutants		
- "criteria"	yes	respiratory effects of NO ₂
- individual organics	(yes)	covered by other EPA programs, other agencies
- organic mixtures	yes	exposures to VOCs, bioassays of combustion organics
- radon	(yes)	epidemiological studies by DOE, EPA
- asbestos	no	covered by Federal Asbestos Task Force
- biocontaminants	no	allergen/pathogen studies by CPSC, HHS, others
o approaches		
- bioassays	yes	bacterial mutagenicity
- animal exposure	(yes)	covered by other EPA programs, other agencies
- human exposure	yes	exposures to VOCs
- epidemiology	(yes)	respiratory effects of NO ₂ , cancer incidence from radon in well water
- risk assessment	(yes)	cancer risks of organics
<u>Evaluation of indoor air quality controls</u>		
o ventilation	no	covered by DOE, utilities
o source modification	no	source characterization research relevant, however
o air cleaning	(yes)	central-system particle controls

Note: (yes) indicates support derived primarily from EPA's "base" research program.

Organizational abbreviations:

CPSC Consumer Product Safety Commission
 DOE Department of Energy
 EPA/OTS EPA/Office of Toxic Substances
 HHS Department of Health and Human Services
 NIOSH National Institute for Occupational Safety and Health

has responsibilities for regulations and state support programs. The design of the radon survey was therefore delivered by Research and Development to Radiation Programs in 1985 for funding and implementation.

The next field survey to be designed was of the combustion pollutants NO_2 , inhalable particles, particle-bound organics, and CO, which come predominantly from unvented cooking and heating appliances and from smoking. Formaldehyde measurements were also to be included. This survey design covered about 2500 homes chosen at random from the nationwide coterminous 48-state total of about 80 million homes. The design was a multi-stage area probability plan, with the final selection of homes stratified based on the presence (or absence) of smokers, heating fuel type, and cooking fuel type. Review of this design by EPA and the CIAQ agencies led to the decision to expand coverage of pollutants, to more closely respond to Congressional guidance for a "multipollutant" survey and to focus greater attention on toxic compounds of regulatory interest to EPA.

The Agency's special concerns about indoor organics are based primarily on: (1) considerable data from European and U.S. field studies showing the presence of many indoor organics at or above concentrations at which criteria pollutants are currently regulated (e.g., 50 to 100 $\mu\text{g}/\text{m}^3$); (2) findings that these compounds are nearly all at higher concentrations indoors than in the nearby outdoor air, which suggests indoor sources; (3) growing regulatory concerns about "air toxics," most of which are organic compounds, and many of which are being found indoors; and (4) field study evidence from both Europe and the United States that many "sick building" complaints may be caused by organic air pollutants.

A national multipollutant field survey is now being designed. It will cover combustion pollutants (NO_2 , particles, and volatile and particle-bound organics) and volatile organic compounds such as those that come from building materials and consumer products. It will be phased, most likely over a 2-year period, covering approximately 1500 homes in 50 different geographical locations. At present, pilot studies by Oak Ridge National Laboratory are being funded, to help evaluate sampling and analytical methods and to develop the details of survey protocols.

Parallel efforts to develop and validate the performance of field sampling methods have been underway since 1984. Instrumentation evaluated to date includes:

<u>Pollutant(s)</u>	<u>Instrument(s)</u>
Radon	Terradex (passive)
NO_2	Palmes sampler (passive)
CO	GE (active integrating) Bag samples (active integrating)
Formaldehyde	LBL, DuPont (passive)
Respirable particles	LBL, Harvard, NBS (active integrating)

Pollutant(s)Instrument(s)

Vapor-phase organics

Tenax (active and passive integrating)
Evacuated stainless steel canisters

Particle-bound organics

Filters, XAD backup

Results of these evaluations are summarized in the Agency's 1985 status report². Several more detailed reports have been published on methods for volatile and particle-bound organics^{4,5,6,7,8}.

No part of the EPA field survey program involves investigation of subjective measures of acceptability by building occupants, since no attempt is made to select problem buildings or residents who are particularly sensitive to odors or irritant chemicals. Also, due to the high cost, no measurements are made of source emissions or health conditions of the residents. For each home, however, the questionnaire being designed may include questions on sources and selected health effects that may be relatable to indoor air pollutants.

CHARACTERIZATION OF SOURCES

Source characterization research includes measurements of emissions from indoor sources and the factors that affect their emission rates. The emissions data can then be modelled to predict indoor concentrations and rank the importance of the sources. Emissions are characterized chemically, and sometimes biologically (e.g., by mutagenesis bioassays to obtain a measure of potential for causing cancer). The ultimate objective of this program area is to determine the most important sources of indoor air pollutants, and to characterize them in a way that will help determine the most cost-effective ways to control their emissions. Intermediate objectives include: (1) providing guidance to field studies of indoor air quality, regarding sources to be accounted for and pollutants to be measured; and (2) providing a database on sources and their emissions, for use in guiding research, investigating sick building problems, and helping pollutant-sensitive people avoid certain sources.

The emphasis of this part of the program has been on developing testing procedures for measuring organic compound emissions from combustion sources (to date, kerosene heaters) and building materials (to date, a variety of pressed-wood products, adhesives, flooring materials, and paints). Particle-bound, semi-volatile, and vapor-phase organic emissions from kerosene heaters are being chemically characterized and bioassayed by bacterial mutagenesis assays, based on samples collected in a room-sized (27 m³) chamber at Lawrence Berkeley Laboratory. Vapor-phase organic emissions from building materials and consumer products are being measured in a small-chamber test facility (170 liters per chamber) at EPA's research center in Research Triangle Park. Details of the testing procedures and emission results are discussed elsewhere^{9,10,11,12}.

Although activities such as cooking, cleaning, polishing, and painting are thought to be major sources--at least episodically--of indoor organics, no current work is underway in the EPA research program. Research of this

nature in the United States is currently limited to studies of methylene chloride emissions during use of certain consumer products like paint, lubricants, and paint strippers. These studies are funded by the Consumer Product Safety Commission as part of their indoor air quality program, and by EPA's Office of Toxic Substances, as part of their regulatory investigations of exposures to methylene chloride from consumer products.

The outdoor environment can also be a source of indoor air pollutants at times. Automobile exhaust and smoke from wood stoves are two recognized sources that can infiltrate into buildings. Soil and groundwater (including well water) can also contribute; radon normally enters this way, and organic compounds enter some buildings because of soil and groundwater contamination. EPA's indoor air research program does not yet address such sources, however. The Department of Energy has funded research on radon entry into homes for several years, and has recently joined EPA's radon mitigation project to help diagnose the interactions between soil gas transport mechanisms and radon reduction techniques. Wood smoke infiltration is being measured under other programs in EPA. Entry of organics via well water and soil gas is being investigated, mostly by states, when complaints arise, but there is no organized research program in this area.

ESTIMATION OF EXPOSURES

Estimates of exposures to indoor air pollution--i.e., the product of pollutant concentration and the volume breathed over a relevant period of time--can be obtained in a number of ways. The EPA research program is obtaining such estimates in two ways, and other EPA programs are obtaining them in a third way. First, data from field surveys of indoor air concentrations are used to obtain exposure estimates, based on concentrations measured in different parts of the home and assumed activity patterns of the residents. Second, emissions data from source characterization tests in chambers are modeled to predict indoor concentrations as functions of time and indoor environmental conditions; assumed activity patterns are then applied to obtain exposure estimates. The third approach involves personal monitoring, where the measured concentrations and personal activity patterns are more directly linked. This last approach is not currently used in the IAQ research program because of difficulties in distinguishing indoor from outdoor exposures for organics, but is used in the Agency's total human exposure research program.

ESTIMATION AND MEASUREMENT OF HEALTH RISKS

The adverse health endpoints of potential concern are nearly as varied as the pollutants found indoors. The primary health effects associated with indoor air quality problems for the past several years have been the odor and irritation complaints that comprise the "sick building syndrome;" i.e., irritation of eyes, nose, and throat; dry mucous membranes and skin; mental fatigue and headaches; airway infections and cough; hoarseness of voice; unspecific hypo-reactivity reactions; and nausea and dizziness¹³. In more recent years, concerns regarding lung cancer have arisen, partly with respect to radon, but also with respect to PAHs from tobacco smoke, and formaldehyde and chlorinated solvents from indoor materials and consumer products. An emerging concern is with neurobehavioral effects such as decreased memory and motor skills, and reduced attention span.

Recognizing the complexity of potentially important health endpoints, and recognizing the limited resources to address very many of them, the initial health studies were of three types. Mutagenesis bioassays were made of air samples from homes with various types of combustors (gas stoves, smoking, wood stoves, plus all-electric homes without any indoor combustion) and the source emission samples from kerosene heaters mentioned earlier¹⁴. Results are now being evaluated and used in preliminary comparative risk assessments of emissions from the various types of indoor combustion sources. They are being compared with comparable risk numbers that have been generated in past years for industrial processes.

A second type of health study was to investigate respiratory effects. Since much work was being done in this area, EPA funds were used to supplement several ongoing studies. Field studies have been funded on the effects of peak exposures to NO₂ on normal adults and children, and on asthmatic adults. Persons in the cohort who are immunologically predisposed and move into new or remodeled houses or mobile homes are also being monitored for health effects from formaldehyde.

The third type of health study, in cooperation with the Consumer Product Safety Commission, has been to assess the value of genetic bioassays of air and urine, and selected biochemical markers, as indicators of exposures to NO₂ and cigarette smoke. Urine samples have been collected from children who have been passively exposed to cigarette smoke, wood smoke, or both. Organic extracts were tested for mutagenic activity by the Ames test. Larger-scale studies are now being planned, to determine whether there is a correlation between exposure to passive smoke and mutagens in urine. Related work has been to determine whether biological markers such as hydroxyproline in urine correlate with exposure to NO₂, and cotinine correlates with passive exposure to smoke. Initial results of these studies will be published in late 1986 or early 1987.

A fourth effort, initiated this year, is to look at the irritant and neurobehavioral effects of typical indoor volatile organic compounds in controlled human exposure studies such as have been done in Denmark¹⁵. A small, multidisciplinary group of researchers from EPA, universities, and the Department of Energy is now developing a protocol for such studies, which are expected to begin in 1987.

Pollutants covered by the IAQ health studies are now virtually all organics. They include gas-phase constituents in the irritant and neurobehavioral studies, and particle-bound or semi-volatile organics for cancer-related studies. Studies of NO₂ that were part of the initial phase of the program have been phased out, since NO₂ is sufficiently covered in the Agency's "base" research program. As in the other two major components of the EPA research program (field survey, source characterization), health studies are now oriented toward organic compounds and mixtures.

Approaches to health effects studies are focussed on bacterial mutagenesis bioassays (cancer endpoint), controlled human exposure studies (irritant/neurobehavioral endpoints), and risk assessments based on existing health effects to work with the Department of Health and Human Services regarding their third national study of health and nutrition (National Health and

Nutrition Examination Survey, NHANES III) which is scheduled to begin in 1988 and continue through 1993. At present, several questions related to indoor air quality or indoor air pollution sources are being evaluated for inclusion in the NHANES III housing characteristics questionnaire. The use of passive samplers (e.g., for NO₂, radon, and formaldehyde) in a subsample of NHANES III homes is also being evaluated.

EVALUATION OF INDOOR AIR QUALITY CONTROLS

Research and development of IAQ controls has been almost exclusively limited to a project on low-cost methods for preventing entry of radon-containing soil gas into homes. Extensive development of techniques for sealing, depressurizing, and pressurizing basement walls, floors, and surrounding soil has been completed in 18 homes in eastern Pennsylvania¹. This project has now moved on to an expanded program in Pennsylvania and other states. Removal of radon from well water has been tested to a limited extent in this project; additional research is underway as part of EPA's "base" research program in drinking water treatment.

A much smaller effort to characterize the controllability of indoor particles was initiated in 1985. Comprehensive measurements have been made of particle concentrations and size distributions in an office building, as functions of location, presence of sources including smokers, and operation of the building ventilation system, including the air filters. Additional measurements are now being made to fully characterize particles with respect to their physical and chemical characteristics, so that optimum designs of filters and electrostatic devices can be evaluated.

SUMMARY

The EPA research program on indoor air quality, now in its third year, is a broad-based program that has the following overall goal: to identify the indoor air pollutants of greatest public health concern, their major sources, and mitigation or avoidance alternatives, so as to provide choices of action at the personal, private sector, or governmental level. The program includes field surveys of pollutant concentrations in homes, characterization of emissions from sources, health studies of genotoxic and irritant/neurobehavioral effects, and a limited amount of research and development of IAQ controls.

The primary emphasis in all areas is on organic compounds, except for controls, where the emphasis is on particles (although even there the orientation is partly organic, since indoor respirable particles are mostly organic condensation aerosols). The area of greatest overall emphasis has been on the national field survey of air quality in homes. This field survey will obtain a national exposure distribution for each pollutant measured and relate indoor and outdoor air pollutants. It will help to define the magnitude of IAQ problems and help confirm whether indoor concentrations are in fact much higher than outdoor concentrations, as suggested by several small field studies that have been done to date. Research on indoor sources, health effects, and IAQ controls will continue to be significant components of the program. In addition, EPA's base programs in air pollution research are likely to become increasingly influenced by indoor air quality concerns.

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